Cross section of hadron production in $\gamma\gamma$ collisions at LEP

L3 Collaboration

Outline:

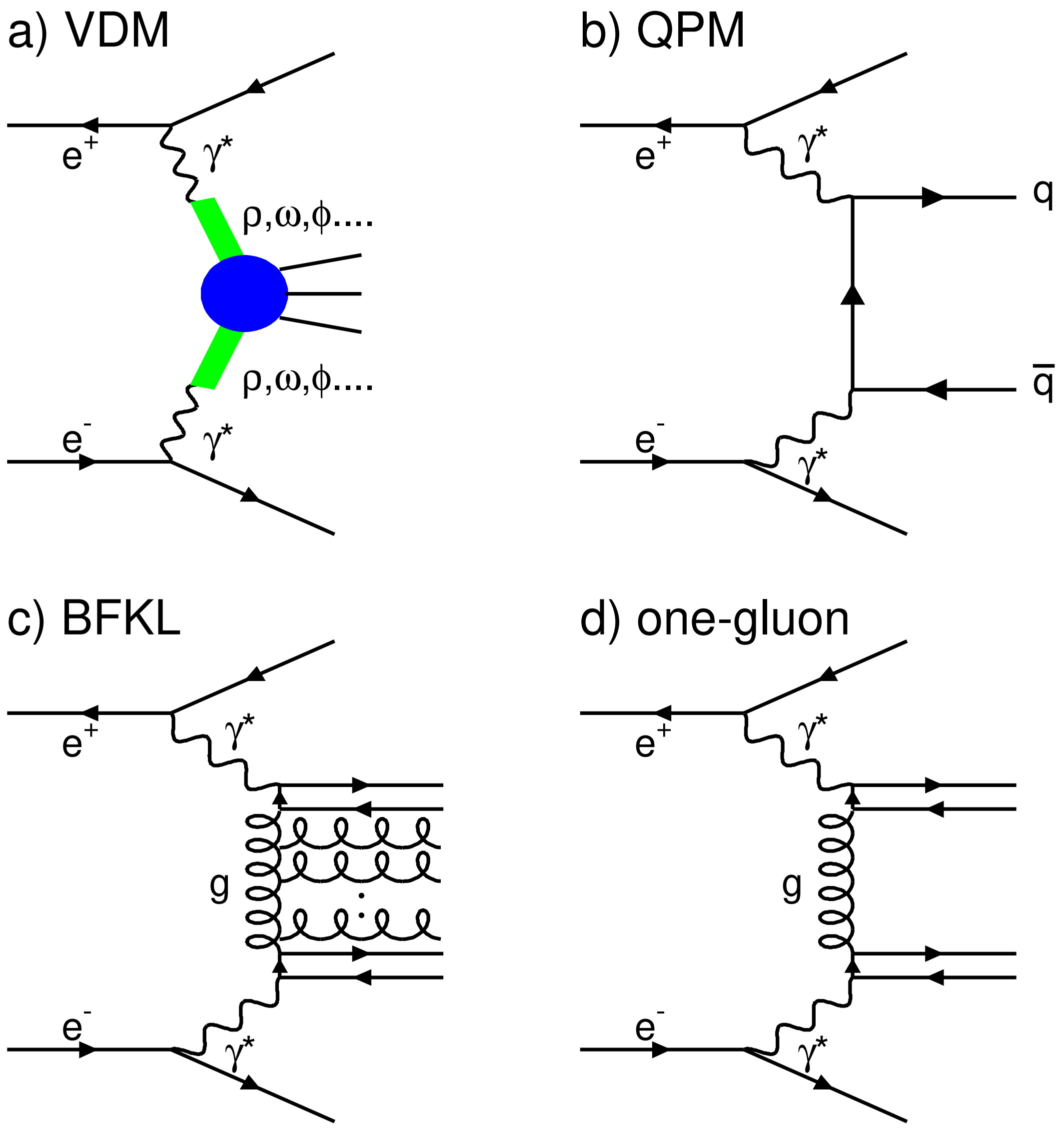
- Introduction
- Event selection
- Monte Carlo (signal and background)
- Data analysis (event selection, MC comparison, cross sections)
  - Quasi-real $\gamma^*\gamma^*$ interactions (anti-tag events)
  - "Deep" inelastic $\gamma^*\gamma^*$ collisions (double-tag events)
- Summary and outlook

process:

$$e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- hadrons$$

- Large hadron production source
- Most of the initial energy is taken by the scattered electrons (often undetected)
- Large part of hadrons escape because of
  - Diffractive processes
  - Low mass hadron system
  - Lorentz boost of $\gamma\gamma$ system
- measured invariant mass W_{vis} smaller then $W_{\gamma\gamma}$
- But for large $\sqrt{s}$:
  good separation of W_{vis} from e^+e^- annihilation

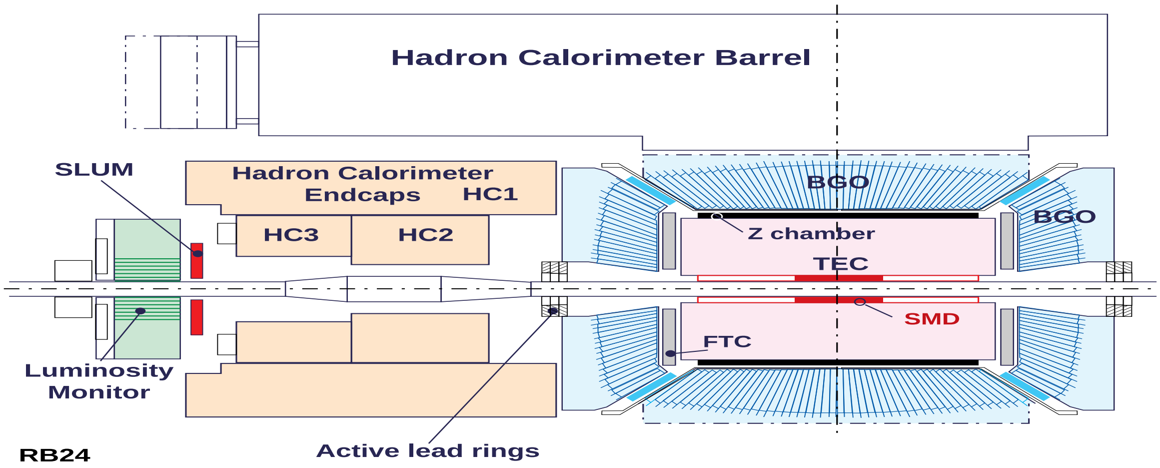
Some diagrams contributing



a) vector meson dominance
b) direct interaction
c) double resolved hard scattering - BFKL Pomeron
d) double resolved hard scattering - one gluon exchange

Harald Vogt
DESY Zeuthen

The L3 LUMInosity Detector



- Small angle electromagnetic calorimeter
  - Silicon strip detector of 3 layers
  - Calorimeter made of Bismuth Germanium Oxide
- Angular coverage:
  - for θ between 27 and 64 mrad at 133 GeV
  - for θ between 33 and 64 mrad at larger energies (shielding included)

Events selected for $\gamma\gamma$ collisions:

- First level trigger condition:
  two charged tracks "back to back" (within $\pm 61°$)
  with $p_t > 150$ MeV
- Quasi-real photons:
  - Scattered e^+e^- are strongly suppressed (antitagging)
    - em. energy seen in the LUMI calorimeter < 50 GeV
  - At least 6 particles are detected
    (to eliminate the $e^+e^- \rightarrow e^+e^- leptons$ channels)
  - Total energy deposited in L3 ECAL > 500 MeV
    (suppress beam-gas and beam-wall background)
  - Total energy measured in the calorimeters < 50 GeV
    (exclude annihilation events)
- Virtual photons:
  - Scattered e^+e^- are detected (double-tagged)
    - em. energy seen in the LUMI calorimeter > 40 GeV
    - polar angle of e^+, e^- between 30 and 60 mrad
  - At least 3 tracks coming from the interaction vertex with
    - $20° < \theta < 160°$
    - $p_t > 100$ MeV
  - Total visible invariant mass of event > 2 GeV

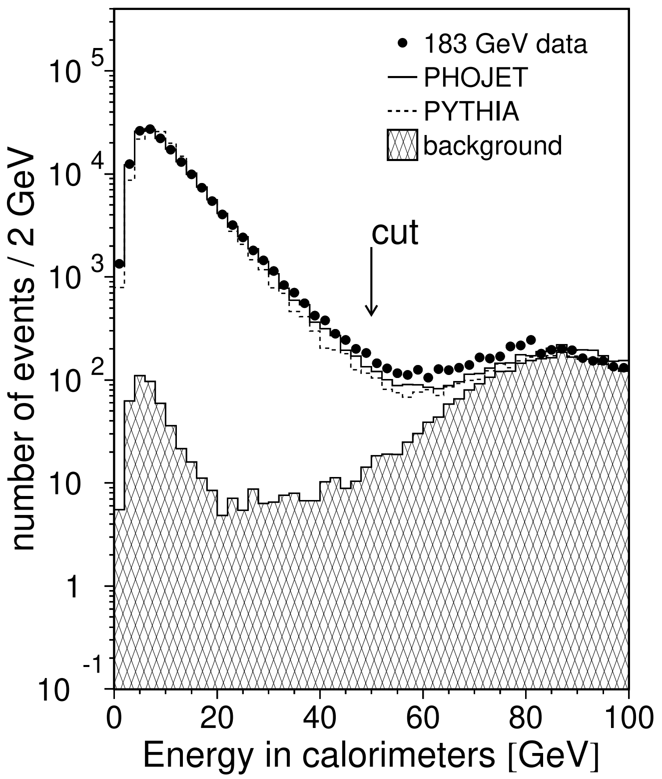
Monte Calo generators used:

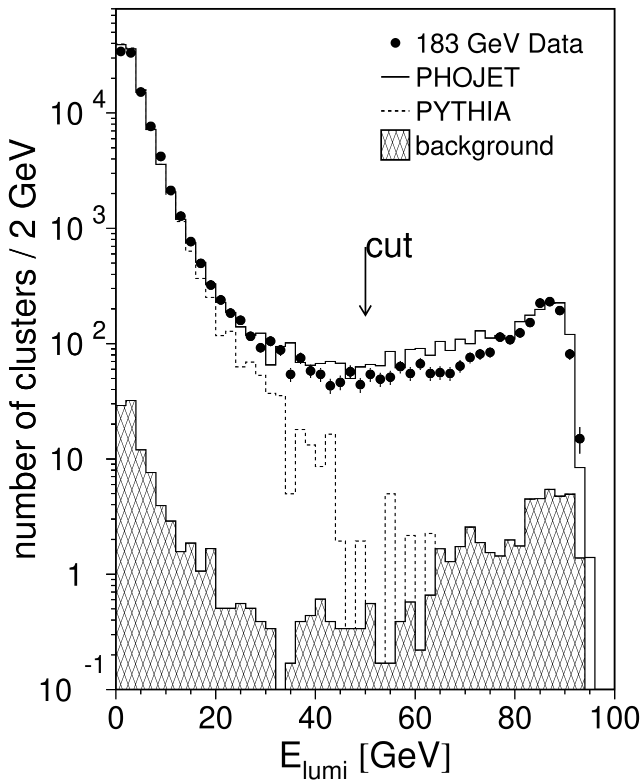
- Quasi-real $\gamma^*\gamma^*$ interactions:
  - Signal
    - for $e^+e^- \rightarrow e^+e^- hadrons$: PHOJET and PYTHIA
  - Background
    - for $e^+e^- \rightarrow hadrons(\gamma)$: PYTHIA
    - for $e^+e^- \rightarrow ZZ(\gamma)$: PYTHIA
    - for $e^+e^- \rightarrow \tau^+\tau^-(\gamma)$: KORALZ
    - for $e^+e^- \rightarrow W^+W^-$: KORALW
    - for $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$: DIAG36
- Virtual $\gamma^*\gamma^*$ collisions:
  - Signal
    - for $e^+e^- \rightarrow e^+e^- hadrons$ (183 GeV): PHOJET, TWOGAM
    - for $e^+e^- \rightarrow e^+e^- hadrons$ (189 GeV): PHOJET, Vermaseren
  - Background
    - for single tagged $e^+e^- \rightarrow e^+e^-\gamma^*\gamma$ reactions: PHOJET
    - for $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$: Vermaseren

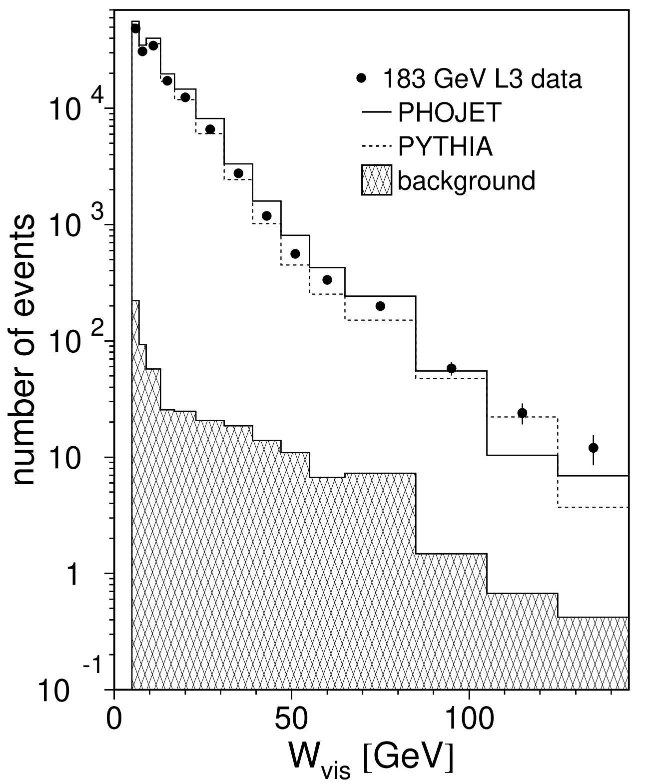
Quasi-real $\gamma^*\gamma^*$ interactions

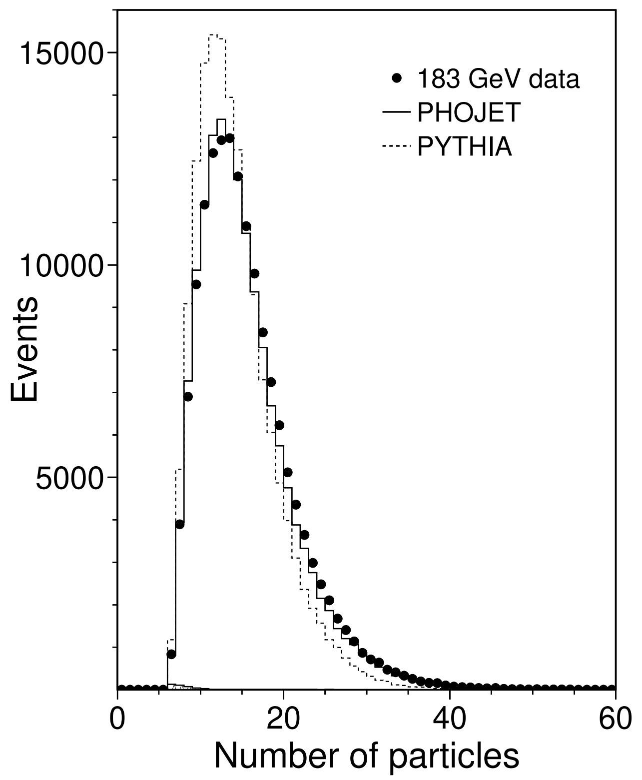
Comparison with Monte Carlo

- Data collected with L3 1997: $\sqrt{s}$= 182.72 GeV, 51.35 pb^{-1}
- The visible effective mass is calculated by:
  $W_{\text{vis}}^2 = (\sum_i E_i)^2 - (\sum_i \vec{p}_i)^2 \qquad i$ = pions, photons
- Analysis restricted to $W_{\text{vis}} \geq 5$ GeV
- Number of events selected: 159012
- Monte Carlo can describe the behaviour of the data
  - PHOJET shows a good agreement in all distributions shown
  - PYTHIA does not describe well all kinematical regions
    (reason: cutoff $Q^2 \leq m_\rho^2$ applied to 2-photon lumi function)
- Background is $\leq 1\%$ (seen in W_{vis} distrubution)


183 GeV data
PHOJET
PYTHIA
background
cut
number of events / 2 GeV
Energy in calorimeters [GeV]


183 GeV Data
PHOJET
PYTHIA
background
cut
number of clusters / 2 GeV
E_{lumi} [GeV]


183 GeV L3 data
PHOJET
PYTHIA
background
number of events
W_{vis} [GeV]


183 GeV data
PHOJET
PYTHIA
Events
Number of particles

Cross section measurement

- Unfolding - Extraction of $W_{\gamma\gamma}$ (true hadron mass) from W_{vis}

  We use
  $W_{\gamma\gamma}(i) = \sum_{j=1}^{n} A_{ij} W_{\text{vis}}(j)$
  for 14 i-intervals in $W_{\gamma\gamma}$ and 30 j-intervals in W_{vis}

  – The matrix A_{ij} is obtained by (from MC sample):

  $$A_{ij} = \frac{P(W_{\text{vis}}(j)|W_{\gamma\gamma}(i))P(W_{\gamma\gamma}(i))}{\sum_l P(W_{\text{vis}}(j)|W_{\gamma\gamma}(l))P(W_{\gamma\gamma}(l))}$$

  with $P(W_{\text{vis}}|W_{\gamma\gamma})$ - likelihood of seeing W_{vis} at given $W_{\gamma\gamma}$

- Now correct for acceptance and efficiency of the detector using the ratio between selected and generated events for each $W_{\gamma\gamma}(i)$

- This is the main source for systematic errors to come in especially for high $W_{\gamma\gamma}$ (> 30 GeV) depending on the MC used (difference in our case $\simeq 20\%$ from PHOJET and PYTHIA)

Cross section measurement

- Cross section of two real photons
  $\Rightarrow$ extrapolation to $Q^2 = 0$

- Calculation of the photon flux $\mathcal{L}_{\gamma\gamma}$(G.A. Schuler, CERN-TH/96-297)

$$d\sigma(e^+e^- \to e^+e^- hadrons)/d\tau =$$
$$\int \frac{d(Q_1^2)}{Q_1^2} \frac{d(Q_2^2)}{Q_2^2} \sum_{a,b=T,S} \mathcal{L}_{ab} \sigma_{ab}(W_{\gamma\gamma}, Q_1^2, Q_2^2)$$

with

$\tau \quad = W_{\gamma\gamma}^2/s$

$Q_1^2, Q_2^2 \quad =$ four momentum transfer squared of e^+e^-

T, S $\quad =$ Transverse, Scalar photon interaction

The scalar contribution is small and σ_{ab} can be factorized for $Q^2 << W_{\gamma\gamma}^2$:

$$\sigma_{a,b}(W_{\gamma\gamma}, Q_1^2, Q_2^2) = F_a(Q_1^2) F_b(Q_2^2) \sigma_{\gamma\gamma}(W_{\gamma\gamma}, 0., 0.)$$

and a numerical integration is perfomed for each $W_{\gamma\gamma}(i)$.

The form factors $F_T(Q^2)$,$F_S(Q^2)$ are taken from a model of J.J. Sakurai, D. Schildknecht (Phys. Lett. B40(1972), 121).

Systematic errors

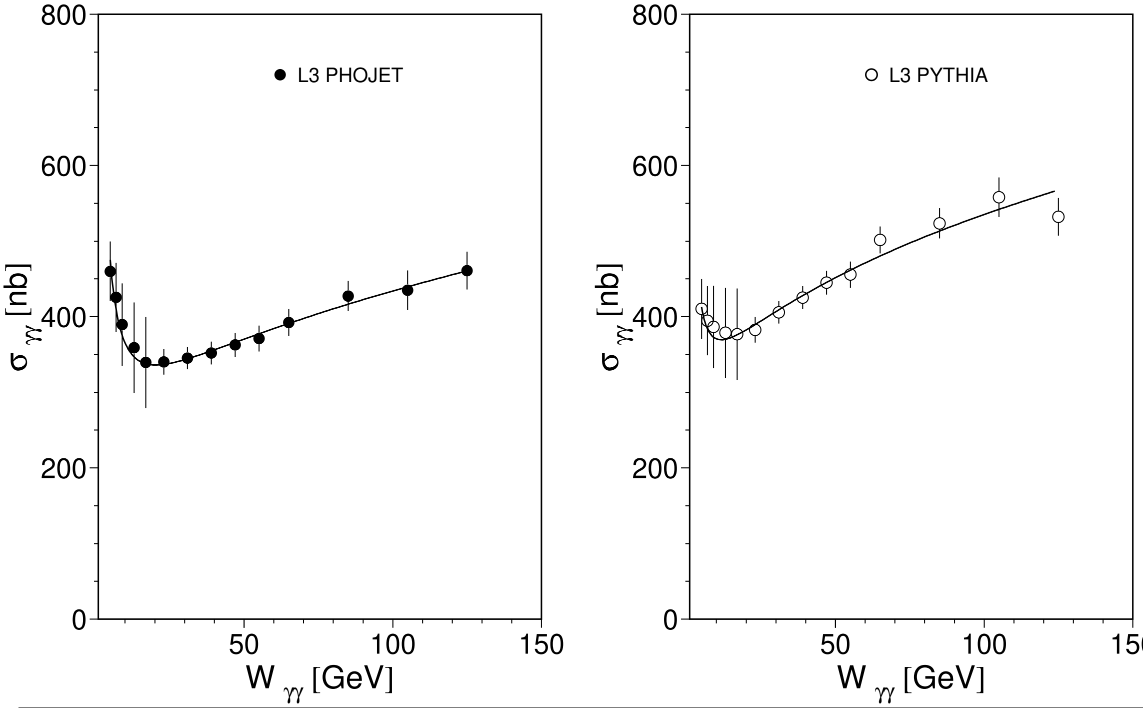
Beside MC uncertainty, main sources are

- trigger rejection (15% below 20 GeV, 4% at higher masses)
- calorimeters energy scale factors (1-3%)
- cut on particle number (5-1%, depending on $W_{\gamma\gamma}$)

The errors given are the combined statistical and systematic errors added in quadrature for each $W_{\gamma\gamma}$ bin.

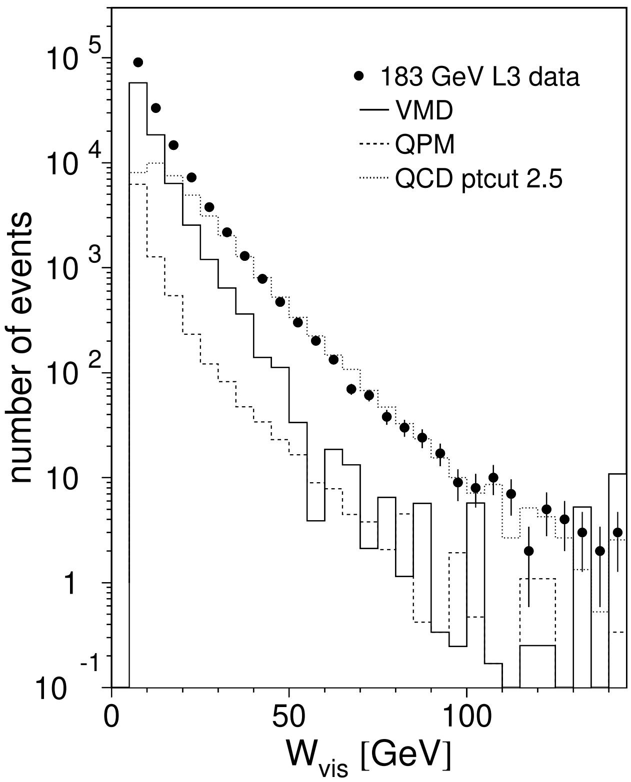
Comparison with Regge theory

- 2 components
  - Regge trajectory ($\alpha_R(0) \simeq 0.5$),
    Pomeron exchange ($\alpha_P(0) \simeq 1$)
- Donnachie, Landshoff parametrisation
  global fit to all hadronic cross sections (πp, pp, np, ...) using
  $\sigma_{\rm tot} = A\, s^{\epsilon} + B\, s^{-\eta}$
  with $\epsilon = 0.0790 \pm 0.0011$ and $\eta = 0.4678 \pm 0.0059$
  (ϵ corresponds to $\alpha_P(0) - 1$, η corresponds to $\alpha_R(0) - 1$)
- fit of data with A, B, ϵ free:
  $\epsilon = 0.158 \pm 0.006$ (stat.) $\pm\ 0.028$ (sys.) (PHOJET corrected data)
  $\epsilon = 0.143 \pm 0.005$ (stat.) $\pm\ 0.025$ (sys.) (PYTHIA corrected data)
  this is a factor of 2 higher



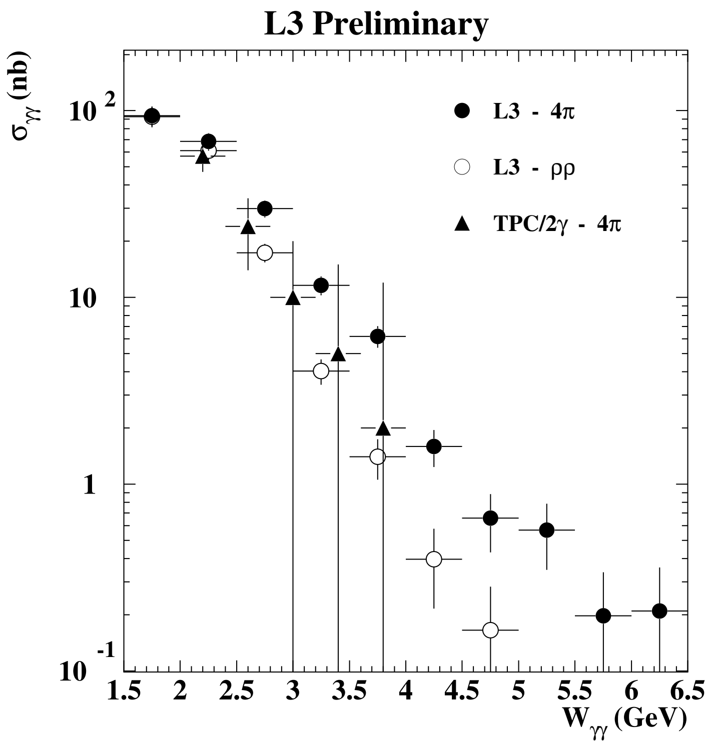
Comparison with QCD models

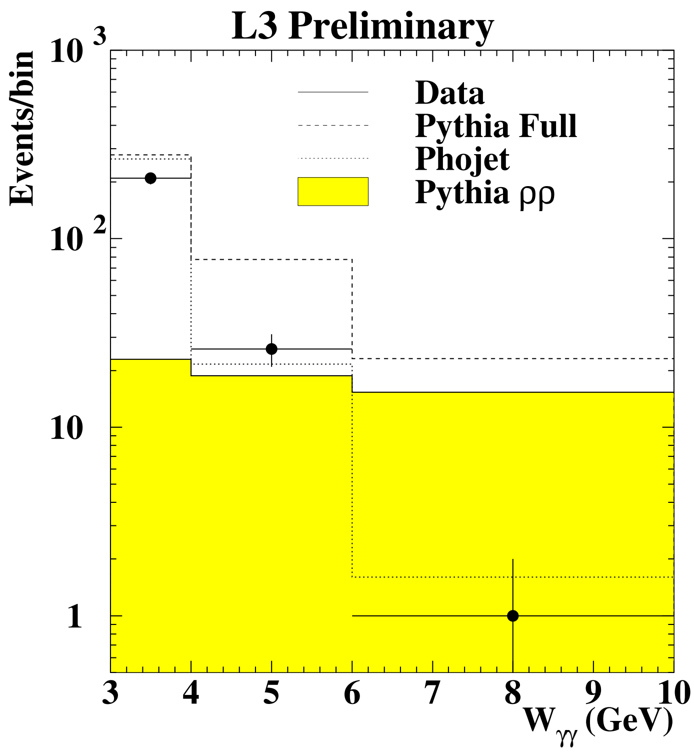
- photon is a superposition of the "bare" photon and the "hadronic" photon (R. Engel, J. Ranft)
- "bare" photon interacts directly (as $\gamma\gamma \to q\bar{q}$)
- "hadronic" photon
  - low mass $|q\bar{q}\rangle$ state → VMD ("soft" hadronic processes)
  - higher mass $|q\bar{q}\rangle$ hadronic state
- two types of $\gamma\gamma$interactions
  - soft hadronic (Regge formalism, Pomeron)
  - hard processes (QCD parton model)
- smooth transition
- comparison with data
  - 3 different models
  - simulated by TWOGAM

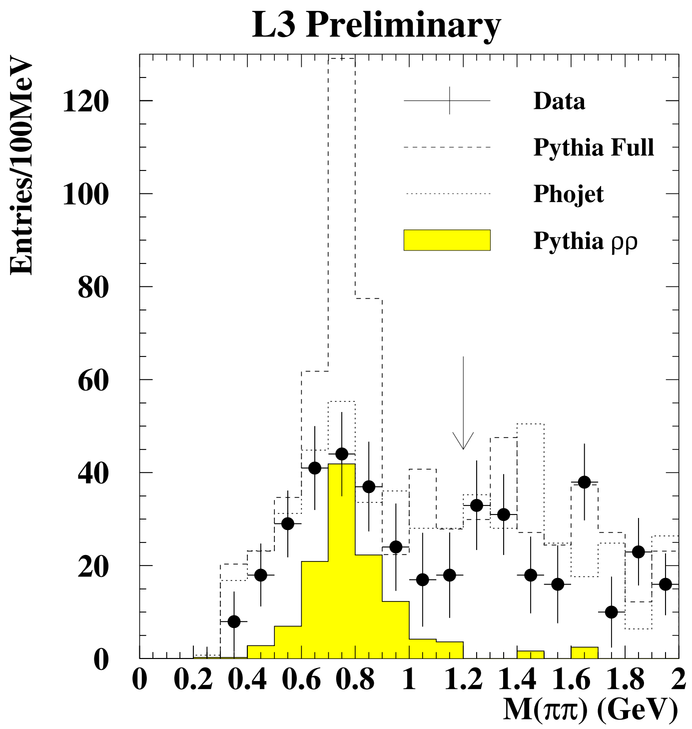


The process $\gamma\gamma \to \rho^0\rho^0$

- Reaction: $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$
- 4 charged tracks with total charge = 0
  coming from the interaction region
  each with $p_t > 100$ MeV
- transverse momenta balanced (< 0.05 GeV^2)
- 6290 events selected
- $\gamma\gamma \to 4\pi$ cross section estimated with
  - correction for acceptance and efficiency
    (Using PC Monte Carlo)
  - $\mathcal{L}_{\gamma\gamma}$ from Low formula (Phys. Rev. 120 (1960) 582)
- $W_{\gamma\gamma} > 3$ GeV (236 events)
- $\rho^0\rho^0$ corrected for wrong combinations
- background from other processes is small
- data compared with PYTHIA and PHOJET


L3 Preliminary
σγγ (nb)
L3 - 4π
L3 - ρρ
TPC/2γ - 4π
Wγγ (GeV)

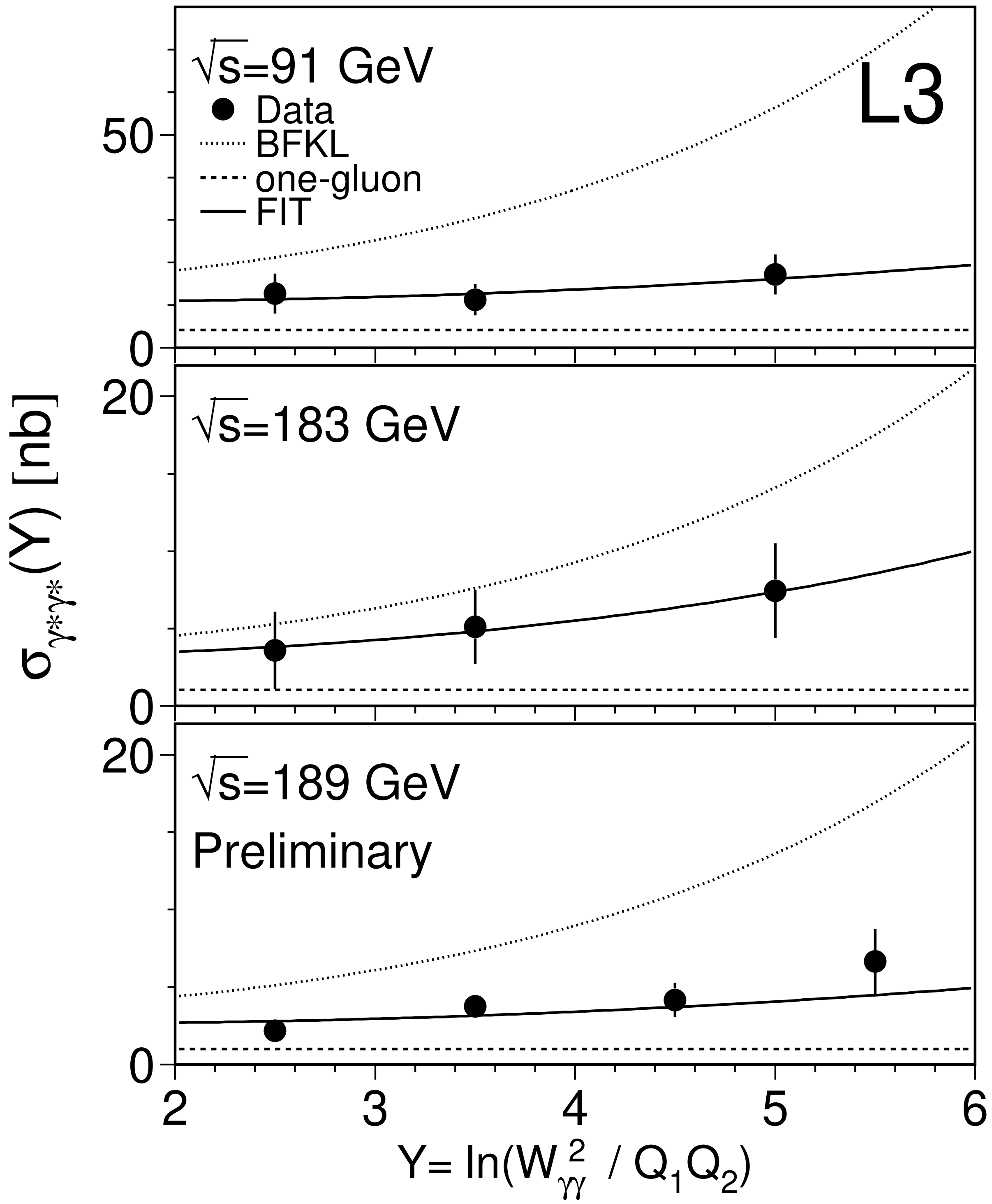

L3 Preliminary
Events/bin
Data
Pythia Full
Phojet
Pythia ρρ
Wγγ (GeV)


L3 Preliminary
Entries/100MeV
Data
Pythia Full
Phojet
Pythia ρρ
M(ππ) (GeV)

Virtual $\gamma^*\gamma^*$ interactions

Test of the BFKL Pomeron

- Data: double-tag two photon events
  - both e^+, e^- are detected in the L3 LUMI detector
  - 1.2 GeV^2 <Q$^2_{1,2}$ < 9 GeV^2 at $\sqrt{s} \simeq$ 91 GeV
    2.5 GeV^2 <Q$^2_{1,2}$ < 35 GeV^2 at $\sqrt{s} \simeq$ 183, 189 GeV
    2 GeV^2 < $W_{\gamma\gamma}$ < 70 GeV^2
- already highly virtual Photons
- event selection
  - number of tracks > 2
  - Y is required to be 2 ≤ Y ≤ 6
    $Y = \ln(\frac{s}{s_0}) \approx \ln(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}})$
  - $W_{vis} > 2$ GeV
- $W_{\gamma\gamma}$ is calculated from the tagged e^+, e^-
  - MC (PHOJET) describes the distribution reasonably
    used for acceptance and efficiency correction
- $\sigma_{\gamma^*\gamma^*}$ extracted from $\sigma_{\rm ee}$
  - using only the transverse photon luminosity function
    (integration program provided by G.A. Schuler)
  - QPM contrubution substracted
- Results: BFKL with α_P as free parameter
  (expected from the model: α_P - 1 ≈ 0.53)



$$\alpha_P - 1 = 0.28 \pm 0.05 \text{ at } \sqrt{s} \approx \ \ 91 \text{ GeV}$$
$$\alpha_P - 1 = 0.40 \pm 0.07 \text{ at } \sqrt{s} \approx 183 \text{ GeV}$$
$$\alpha_P - 1 = 0.29 \pm 0.03 \text{ at } \sqrt{s} \approx 189 \text{ GeV}$$

Summary and Outlook

- We have reached already the transition region from soft to hard $\gamma\gamma$ interactions.
- The cross section behaviour can be described only patially by existing models.
- The BFKL QCD approach does not describe our data at present photon virtuality.
- We are waiting for the coming two years of LEP running with high statistics.

Thanks to the LEP machine crew for the good LEP preformance !